WG 5: ERL Applications

16 presentations: plenary + 3 session

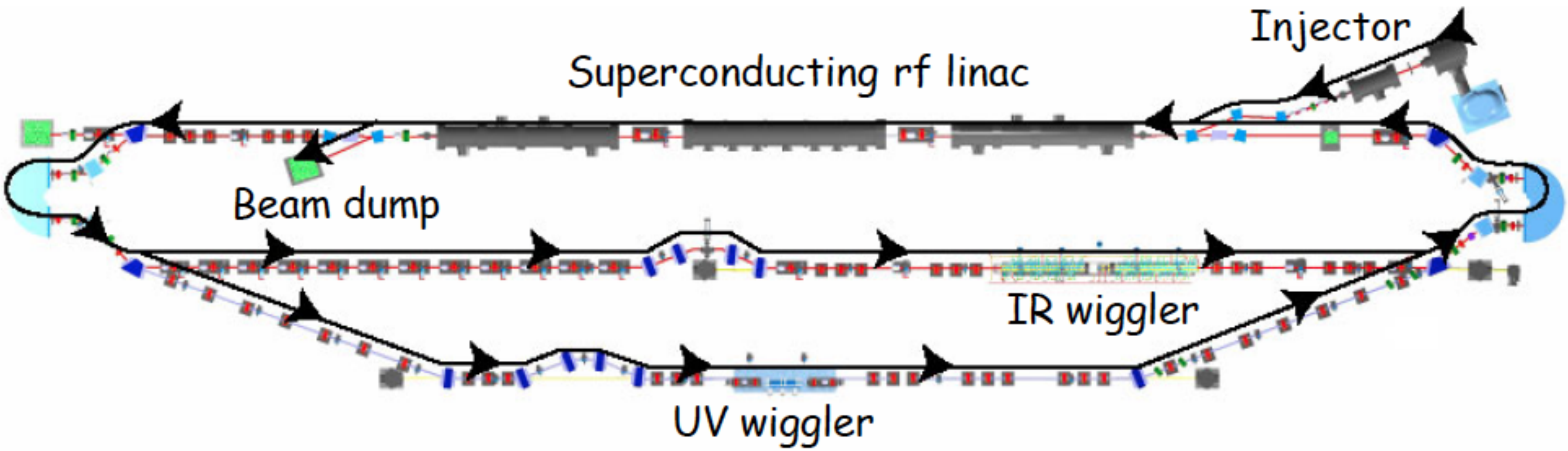
Oliver Brüning

Vladimir N Litvinenko

ERL facilities with user program

- Jlab FEL – high power IR/UV FELs, THz radiation, dark photon search
- Alice – THz radiation, IR FEL, injector in FFAG ring EMMA
- Novosibirsk 4 path ERL – high power THz and FIR FEL
- KEK cERL – in progress

JLab IR and UV FEL

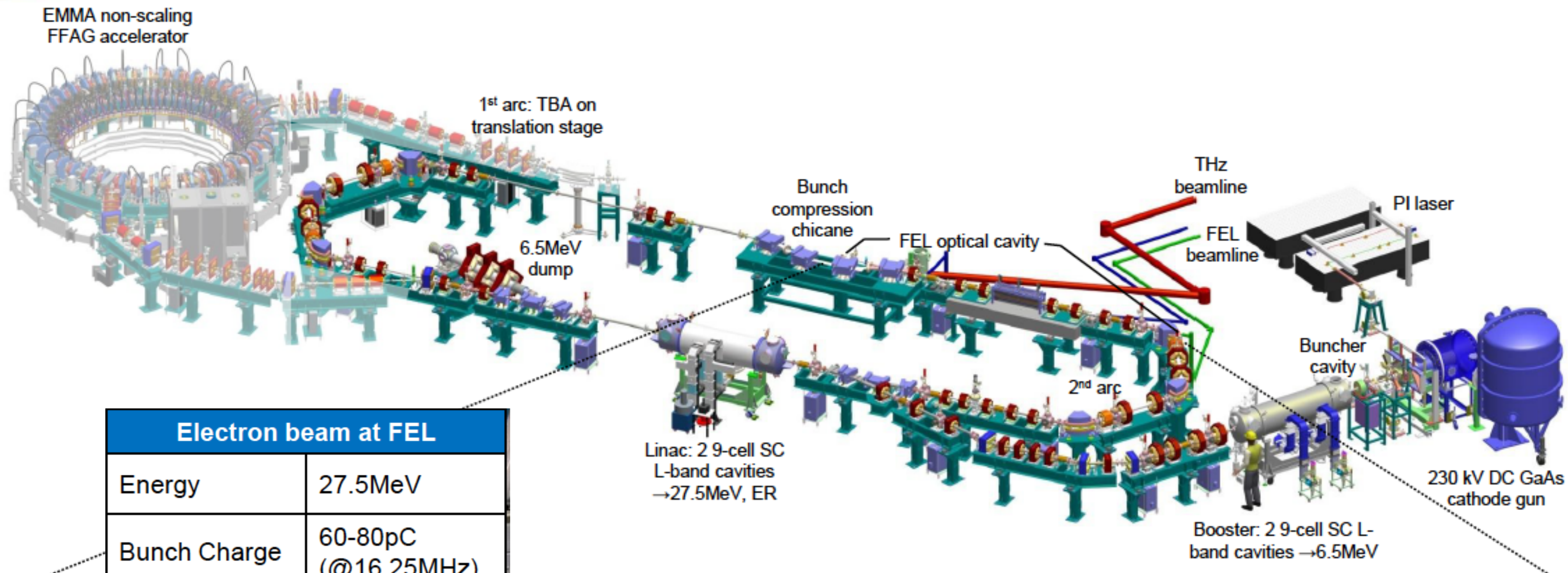


Output Light Parameters	IR	UV
Wavelength range (microns)	1.5 - 14	0.25 - 1
Bunch Length (FWHM psec)	0.2 - 2	0.2 - 2
Laser power / pulse (microJoules)	100 - 300	25
Laser power (kW)	>10	> 1
Rep. Rate (cw operation, MHz)	4.7 – 75	4.7 – 75

Electron Beam Parameters	IR	UV
Energy (MeV)	80-200	200
Accelerator frequency (MHz)	1500	1500
Charge per bunch (pC)	135	135
Average current (mA)	10	5
Peak Current (A)	270	270
Beam Power (kW)	2000	1000
Energy Spread (%)	0.50	0.13
Normalized emittance (mm-mrad)	<30	<11
Induced energy spread (full)	10%	5%

©S. Benson

ALICE ERL FEL



Electron beam at FEL	
Energy	27.5MeV
Bunch Charge	60-80pC (@16.25MHz)
FWHM Bunch Length	~1ps
Normalised Emittance	~12 mm-mrad
Energy Spread	~0.5% rms
Repetition Rate	81.25MHz/ 16.25MHz
Macropulse Duration	≤100μs
Macropulse Rep. Rate	10Hz

Achieved ALICE FEL output parameters, in-vacuum immediately behind the downstream mirror:

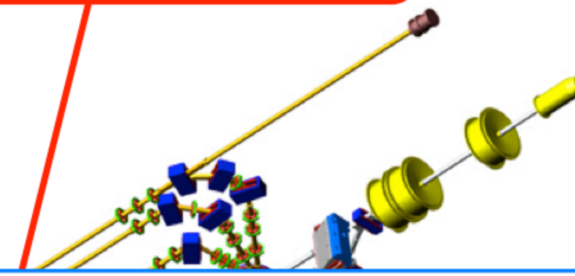
Parameter	Notation	Value
Wavelength	λ_r	5.0–8.0 μm
FWHM Bandwidth	$\Delta\lambda/\lambda$	0.9–1.8 %
Pulse Energy	E_{pulse}	$\leq$ 3.3 μJ
Peak Power	P_{peak}	$\leq$ 3.6 MW
Average Power	P_{avg}	$\leq$ 45 mW
Average Power (within macropulse)	$P_{\text{avg,pulse}}$	$\leq$ 53 W

©D. Dunning

Novosibirsk ERL FEL

The third and the fourth tracks with IR FEL (commissioning)

The first and the second tracks in horizontal plane with bypass for the second FEL (in operation)



Electron Beam Parameters	
Energy (MeV)	12
Accelerator frequency (MHz)	180
Charge per bunch (pC)	900
Average current (mA)	20
Peak Current (A)	10
Beam Power (kW)	240
Energy Spread (%)	0.2
Normalized emittance (mm-mrad)	20

The 1st stage FEL radiation parameters

• Radiation wavelength, mm	0.12 - 0.24
• Pulse duration, ps	70
• Repetition rate , MHz	11.2
• Maximum average power, kW	0.5
• Minimum relative linewidth (FWHM)	$3 \cdot 10^{-3}$
• Peak power, MW	1

The obtained radiation parameters are still the world record in terahertz region.

5

Goals/Charge

- Discuss applications which require ERLs or can benefit from ERLs
- Discuss strengths & weaknesses of ERLs as accelerator used for applications
  - Example of possible weaknesses: (a) difficulty with radiation protection/ beam loss limitations; (b) need to bend electrons and suffer SR losses and effects….
  - Example of obvious advantages: (a) energy efficiency; (b) ability of providing fresh beam very high power; (c) preserve polarization …
- Discuss set(s) of critical parameters which ERLs should demonstrate to become of interest for various applications
  - High energy/nuclear physics (including γ-ray sources)
  - Light sources/FELs
  - Material science/technology
  - Industry (including XUV lithography)
  - …….

“Relevant to ERL applications“ talks

– actually all talks at this workshop are relevant and important for one of foreseen applications

ERL applications talks

- **Operational facilities/science cases**
  - **10 Years of ALICE: From Concept to Operational User Facility, P. Williams**
  - **Science cases on ERL as a synchrotron light source, H. Kawata**
  - **Nuclear and High-Energy Physics Experiments with Cornell's FFAG ERL, M. Perelstein**

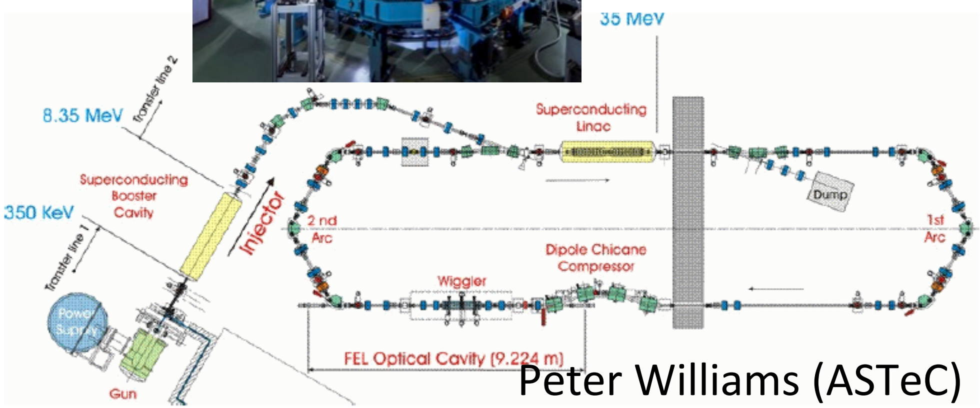
- Colliders/Nuclear physics
  - ERL-based Electron-Ion Colliders, V. Ptitsyn
  - Current Status of the MESA Project, R.Heine
  - ERL facility at CERN for applications, E. Jensen
  - A Lepton Energy Recovery Linac Scalable to TeV, V. Litvinenko
  - Using ERLs for Coherent electron Cooling, I.Pinayev
  - ERL for low energy electron cooling at RHIC (LEReC), J.Kewisch

- Light sources/ FELs/γ-ray sources
  - The Femto-Science Factory: A Multi-turn ERL-based Light Source, T. Atkinson
  - Design work of the ERL-FEL as the high intense EUV light source N. Nakamura
  - ERL as FEL driver, Y.Jing
  - Ultra-High Flux of X-ray/THz Source based on Asymmetric Dual Axis Energy Recovery Configuration, I. Konoplev

- γ-ray sources
  - Laser Compton Sources Based On Energy Recovery Linacs , R. Hajima
  - ERL as high intensity mono-energetic γ-ray sources, V. Yakimenko
  - An Inverse Compton Scattering Beamline for High-Energy, Time-Resolved X-ray Scattering Studies of Materials, G.Hoffstaetter

The Evolution of the ALICE ERL-FEL at Daresbury

- **2000**: Proposed **4GLS** CW ERL driven VUV FEL as user facility (100mA, 600 MeV)
- **2003**: **E**nergy **R**ecovery **L**inac **P**rototype **funded** (pulsed 10 mA in 100us macropulse @ 10 Hz, 35 MeV)
- **2005/6**: Installation & commissioning of 350 keV DC photocathode **gun**, 120W **cryosystem**, 2 SC **Linacs**, recirculation **transport** & oscillator **IR-FEL**. **First beam August 2006**
- **2007**: Problems with gun, RF, cryo
- **2008**: Fixing problems, then **full energy recovery** (initially at reduced gun voltage, linac gradient)
- **2009**: Gun Kr plasma cleaning & leak chasing, RF conditioning & LLRF optimisation
- **2010**: He processing of linac to mitigate FE, then **first lasing of IR-FEL** with full ER at 27 MeV
- **2011**: Diagnosing FEL radiation, Electro-optic bunch length measurements,
- **2012**: **Gun upgrade** -> 325 kV design voltage achieved -> **beam quality** much improved
- **2013**: Installation of DICC 7-cell cryomodule, module & cryo faults -> revert to original linac
- **2012 – 2015**: **Understanding** of machine through transverse & longitudinal beam dynamics studies, **stability of operation** through active feedback, DLLRF, high-level software
- ***2016**: Intended reinstallation of DICC cryomodule*



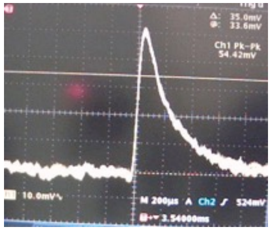
Typical operational parameters

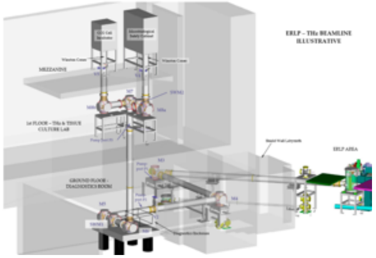
Full Energy (MeV)	24-27
Injector Energy (MeV)	6
Bunch Charge (pC)	60 – 80
Micropulse rep. rate (MHz)	16.25 / 32.5
Radiation Macropulse length (µs)	85 + 15 startup
Number of micropulses / macropulse	1400 / 2800
Macropulse rep. rate (Hz)	10
FEL Wavelength range (µm)	5.5 – 11
Micropulse energy at sample (µJ)	2
Peak power at sample (MW)	2
Av. Power within macropulse at sample (W)	20
Av. Power at sample (mW)	40
Linear polarisation	>95%
Power stability	~0.2 – 1 %

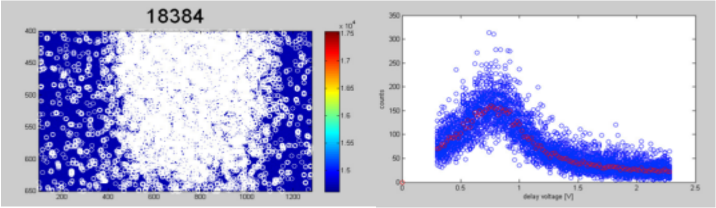
Peter Williams (ASTeC)

The Applications of the ALICE ERL-FEL at Daresbury

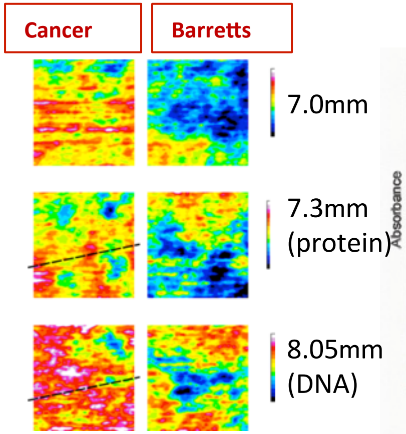
- **2009**: **Coherent THz** used to study effect on living tissue, generation of **Compton back-scattered X-rays**

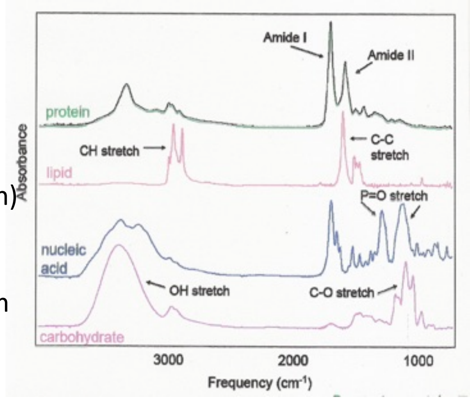






- **2010**: Used as injector for **EMMA NS-FFAG**
- **2011**: **FELIS** – **F**ree **E**lectron **L**aser **I**ntegrated with **S**canning Near-Field Optical Microscope
  - Oesophageal adenocarcinoma often progresses from Barrett's oesophagus: The challenge is to identify patients with Barrett's oesophagus who will develop oesophageal cancer
  - Need to work in the near field with intense, tuneable source
  - Image cluster analysis at 3 wavelengths selected to differentiate the components and quantify the "spreaded-outness" of DNA -> diagnosis





- **2014-2016**: "Towards disease diagnosis through spectrochemical imaging of tissue architecture"
  Extends FELIS programme to prostate & cervical cancers

- **Future**: Bid underway to cement ALICE as an EPSRC mid-range facility

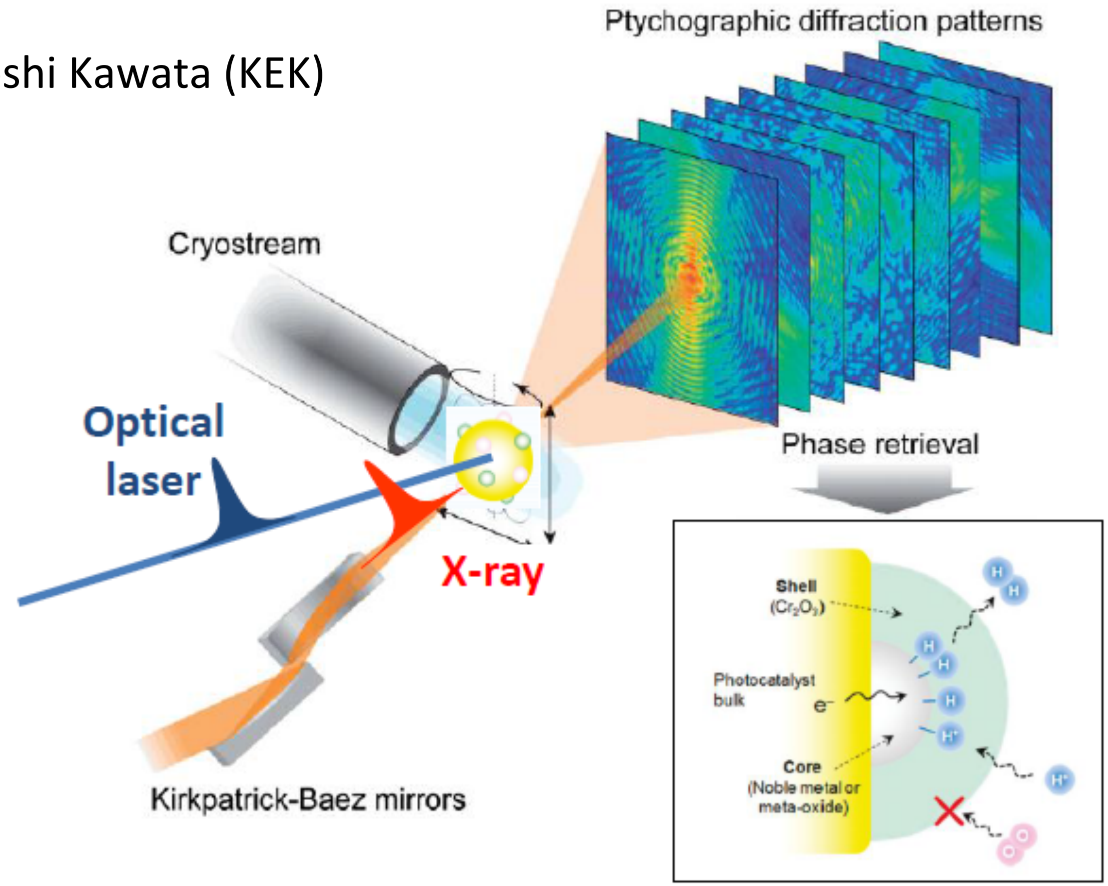
- **ALICE** was intended as a short lived test-bed and learning tool, but has transcended it's original purpose and is now a scientific facility in its own right, as well as a technology test bed

Peter Williams (ASTeC)

One of the examples of ERL experiment

femtosecond pump-probe nondestructive X-ray coherent diffraction imaging

Hiroshi Kawata (KEK)



Courtesy of Prof. Yukio Takahashi (Osaka Univ.) (ERL Conceptual Design Report)

Femtosecond 3D movie of Photo-catalyst in action!

Summary

ERL is a future X-ray light source designed based on state-of-the-art superconducting linear accelerator technology, which will offer far higher performance than the existing storage ring. The **high repetition rate**, **short pulse**, **high spatial coherence and high brightness** of ERL will enable the filming of ultrafast atomic-scale movies and determination of the structure of heterogeneous systems on the nano-scale. These unique capabilities of ERL will drive forward a distinct **paradigm shift** in X-ray science from ***"static and homogeneous" systems to "dynamic and heterogeneous" systems,*** in other words, from ***"time- and space-averaged" analysis to "time- and space-resolved" analysis.***

Hiroshi Kawata (KEK)

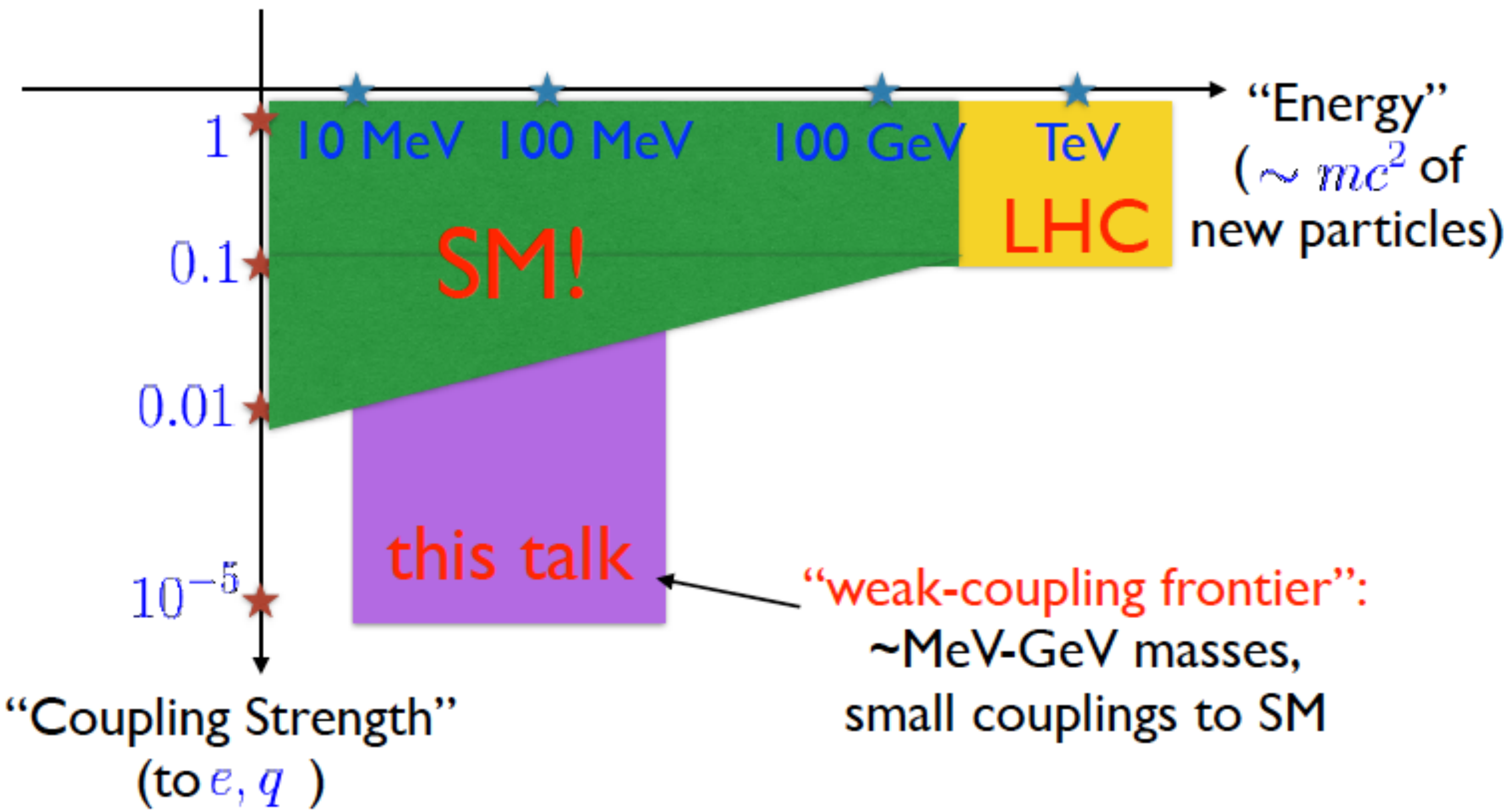
Particle Physics Experiments with Cornell's FFAG ERL

Maxim Perelstein, Cornell University

ERL-2015 Workshop, Stony Brook, June 10, 2015

Frontiers of Particle Physics

- #1 Priority in particle physics is to test the Standard Model, and hopefully find new physics beyond the SM



ERL applications talks

- Colliders/Nuclear physics
  - ERL-based Electron-Ion Colliders, V. Ptitsyn
  - Current Status of the MESA Project, R.Heine
  - ERL facility at CERN for applications, E. Jensen
  - A Lepton Energy Recovery Linac Scalable to TeV, V. Litvinenko
  - Using ERLs for Coherent electron Cooling, I.Pinayev
  - ERL for low energy electron cooling at RHIC (LEReC), J.Kewisch

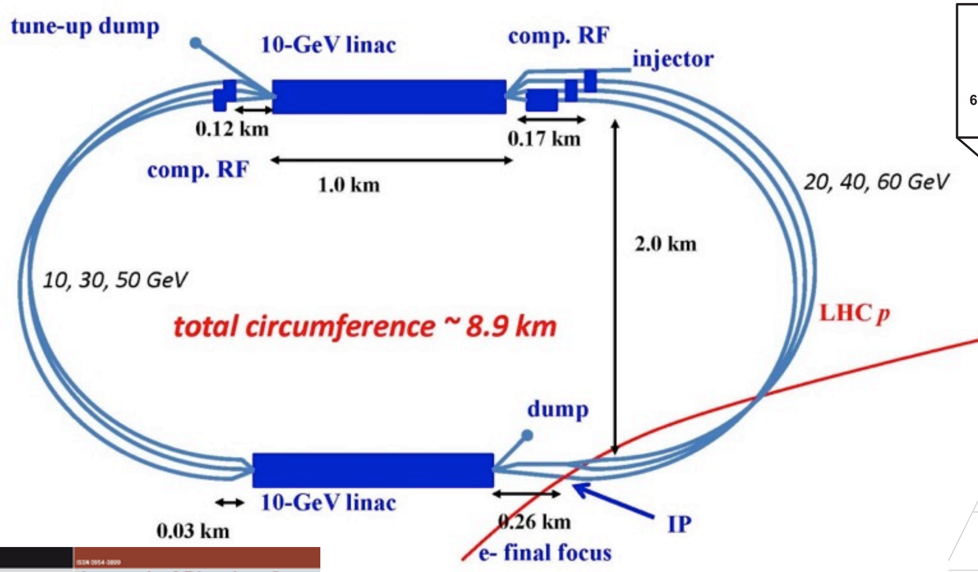
ERL-based Electron-Ion Colliders

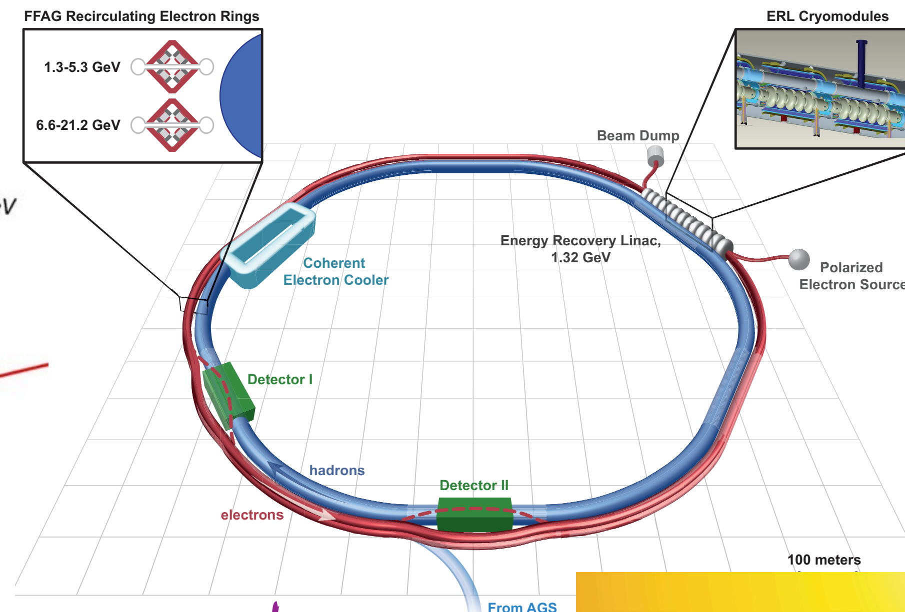
V. Ptitsyn (BNL)

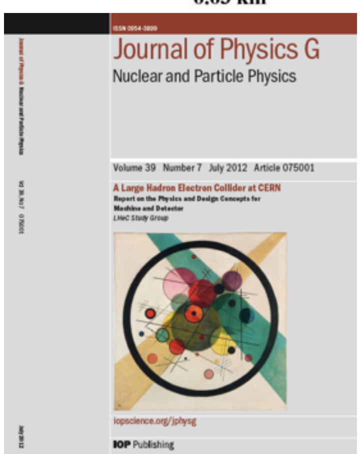
LHeC Linac-Ring

$L \sim 10^{33}\text{-}10^{34}\ cm^{-2}s^{-1}$

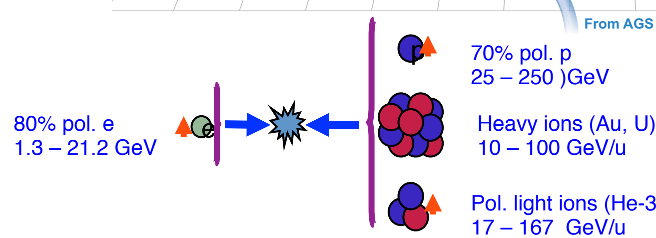
eRHIC

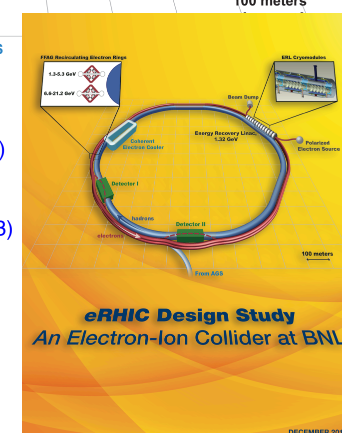




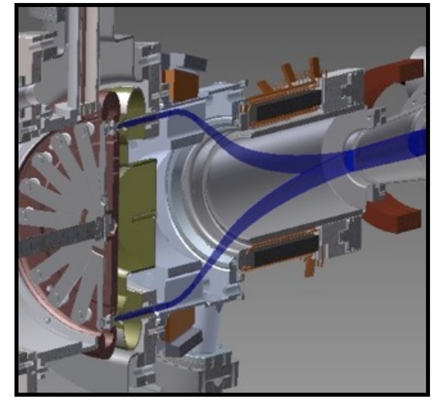


60 GeV (e) x 7 TeV (p)

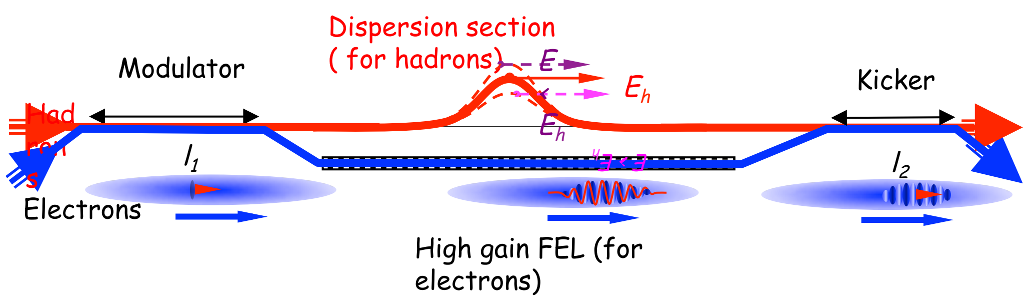




EIC Technological challenges

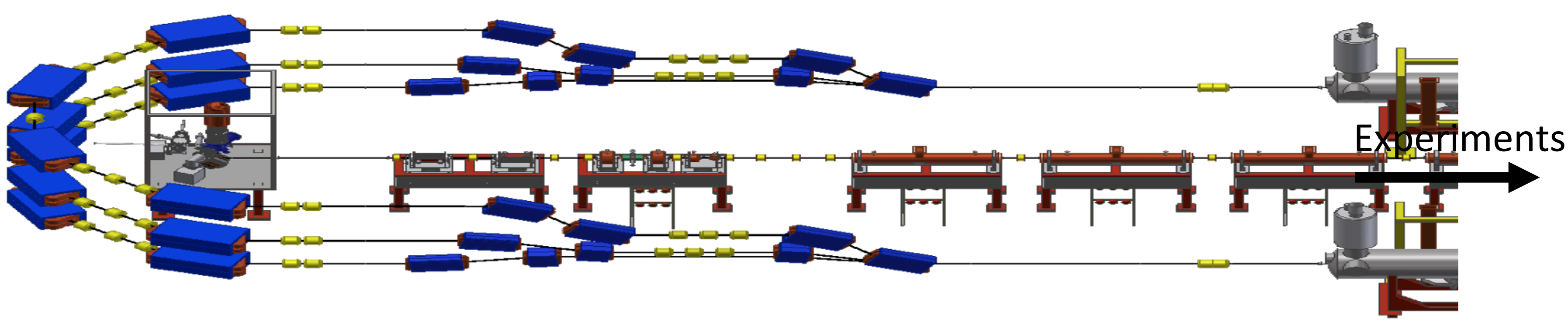


- High intensity (6 – 50 mA) polarized electron source
- High power ERL with multiple re-circulations (high current SRF cavities, machine protection, MBBU, …)
- Strong cooling of hadron beams *(eRHIC)*
- Low hadron b* interaction region
- Crab-crossing *(eRHIC)*
- Beam-beam effects
- Techniques for intense e^+ beam *(LHeC)*



MESA status

- The MESA project group has grown strongly since 2012
- The project is getting closer to completion
- Beam dynamics research and lattice design are mostly finished, magnet design will start in summer.
- MAMBO beam dynamics, RF & thermal design are finished, prototyping and tendering of the structures within the next 12 months
- SRF modules are ordered and shall be delivered in summer 2017
- Particle source and LEBT will be available for commissioning in 2016

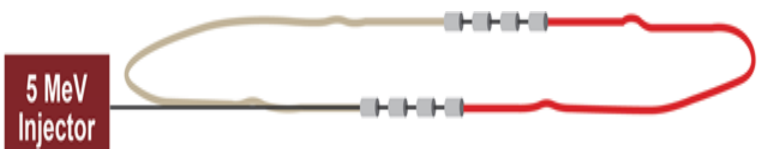


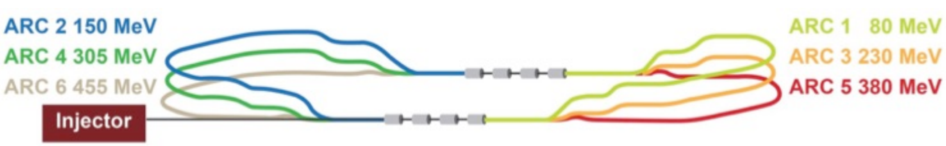
ERL Facility at CERN for Applications, Summary 1/2

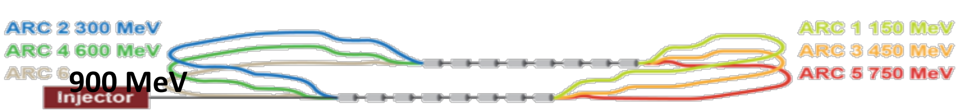
Erk Jensen/CERN

- Small facility to study ERL physics and operation.
- Staged construction 150 MeV … 900 MeV,

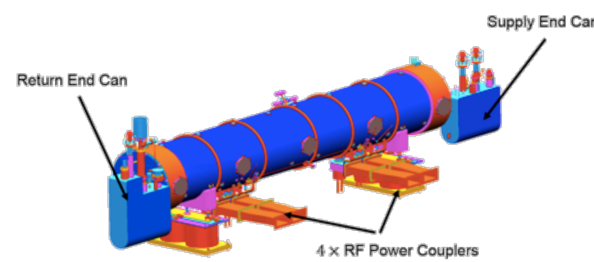
  320 nC ✕ 40 MHz

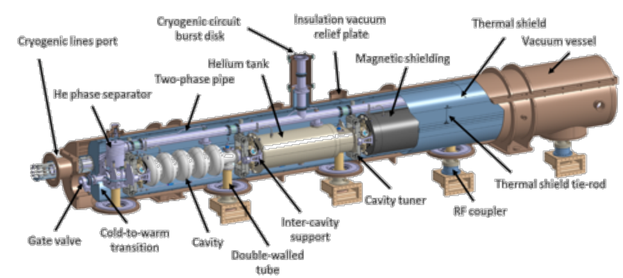






- Application 1: SRF R&D: testing with beam!
- with reduced rep rate (12 MHz), testing possible at 704, 802 and 1300 MHz

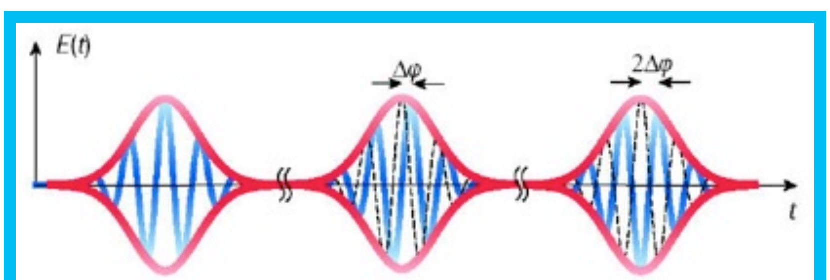




ERL Facility at CERN for Applications, Summary 2/2

Erk Jensen/CERN

- Relevant for LHC, LHC upgrades, FCC study:
  - Test of beam instrumentation
  - Test of beam induced quenches in wires/magnets
- Compton γ-ray source: collide with mode-locked, high power laser with matched pulses – for 30 MeV photons with excellent brilliance/bandwidth.



- ***General conclusions:***
- Keep the design flexible!
- Design the facility such that options for future applications are kept valid!
- Provide space/shielding/ infrastructure to be compatible with the envisaged applications.
- Provide for an extraction from arc6 for non-ER mode operation.

Why CW linac?

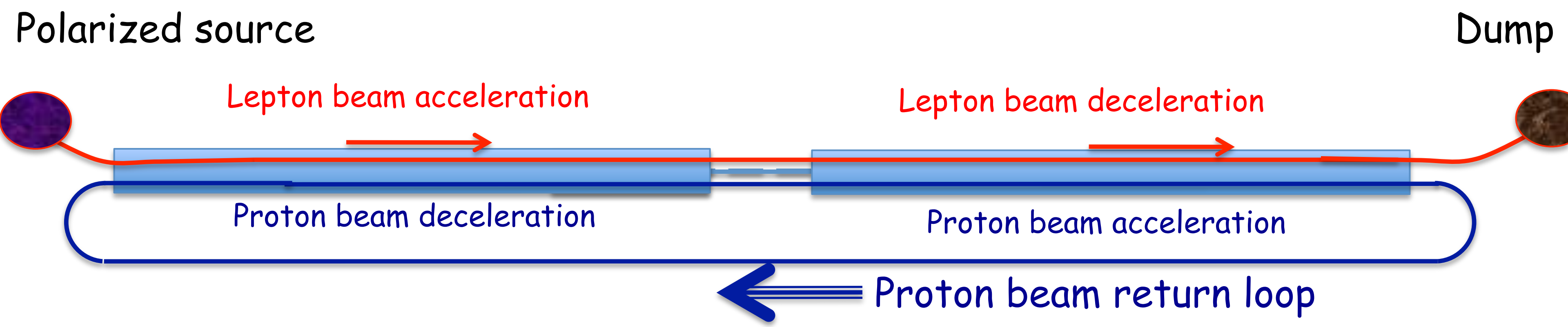
- Synchrotron radiation limits top e+e- energies even in FCC: in relevant units it is

$$P_{SR}[GW] = 88.46 \cdot 10^3 \frac{E_e^4[TeV] \cdot I[A]}{R[km]}$$

- Using linac-ring collider removes one of beam-beam limits and can provide for much higher luminosity
- Preserves polarization during acceleration
- CW e-beam is needed
  - for colliding hadron beam stability
  - for luminosity and avoiding pile-up in detectors

Natural option of high energy high current ERL: proton beam is used to carry the energy

100% energy recovery

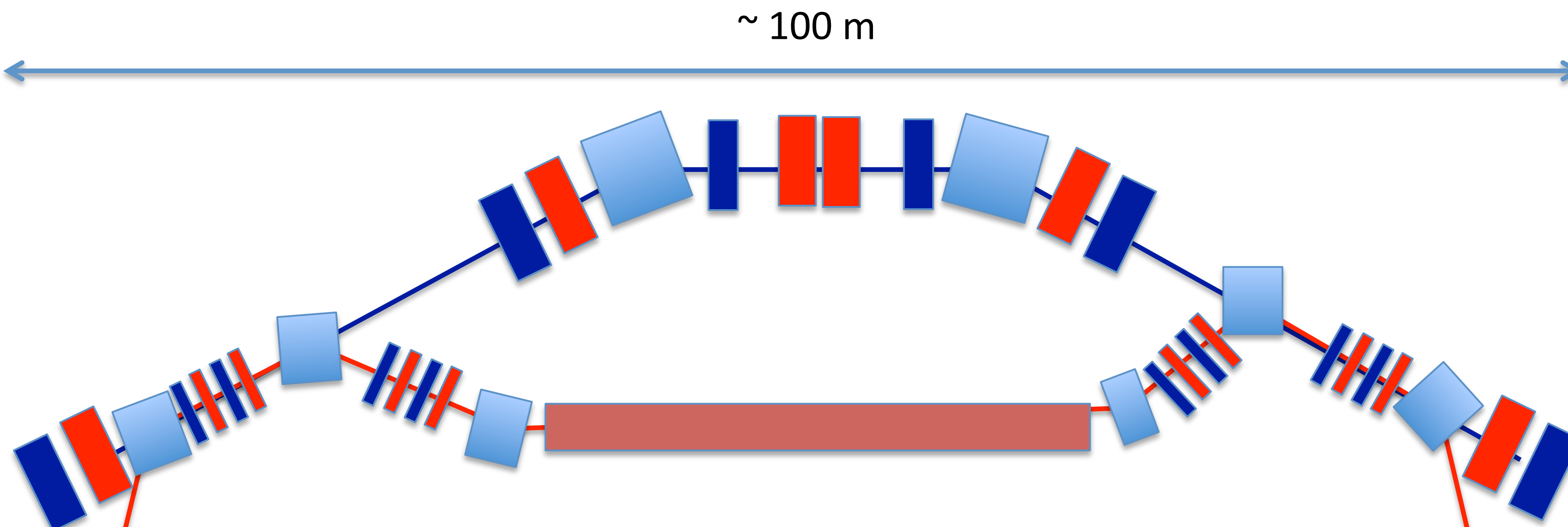


Energy flux is carried out by a proton beam

Synchrotron radiation is reduced ~10^{13} fold to watt level

$$P_{SR}[W] = 7.79\,\frac{E_p^4[TeV]\cdot I[A]}{R[km]}$$

eRHIC CeC Layout

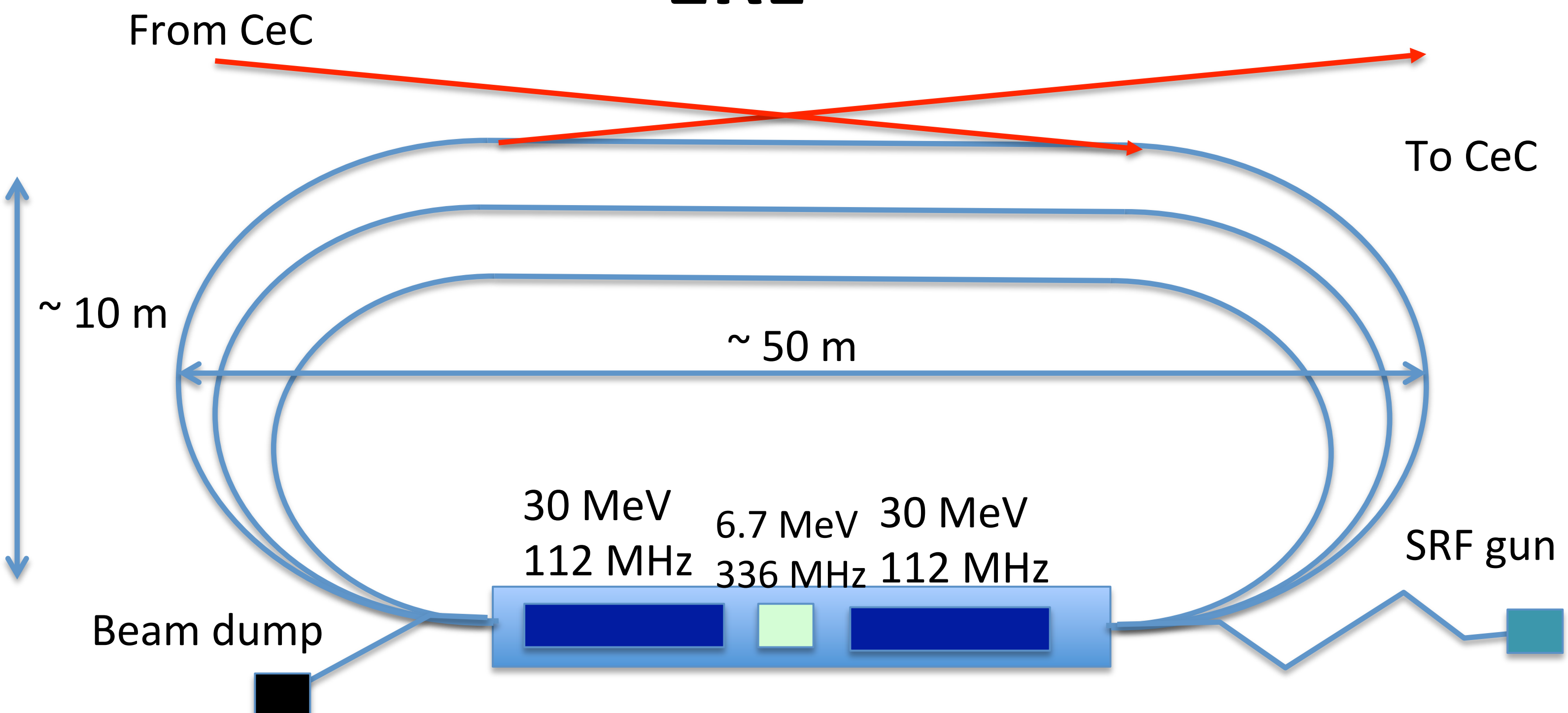


- Hadron beam line:
  - 2 dipoles, 2.5” gap, 1.6 T, 8 m each
  - 12 quadrupoles, 2.5”, 20 T/m, 2.5 m each
  - 20 dipole trims: 10A, 20 V
  - delay and R_{56} are controlled
- Electron beam line
  - 6 dipoles, 2.5” gap, 0.3 T, 0.4 m each
  - 16 quadrupoles, 2.5”, 7 T/m, 0.3 m each
  - FEL: period 4 cm, length 12 m
  - 30 dipole trims: 1A, 10 V

FEL Length 12 meters
Kicker – 20 m
Modulator – 20 m
FEL wavelength 0.56-14 m (50-250GeV)
Delay in FEL 0.185-1.1 mm

Igor Pinayev (BNL)

ERL



Parameter	Value
Electron beam energy	25-140 MeV
Electron beam current	50 mA
Bunch charge	5 nC
Repetition rate	9.38 MHz
Bunch length	0.2 nsec
Normalized emittance	< 3 mm mrad
Relative energy spread	$<10^{-4}$

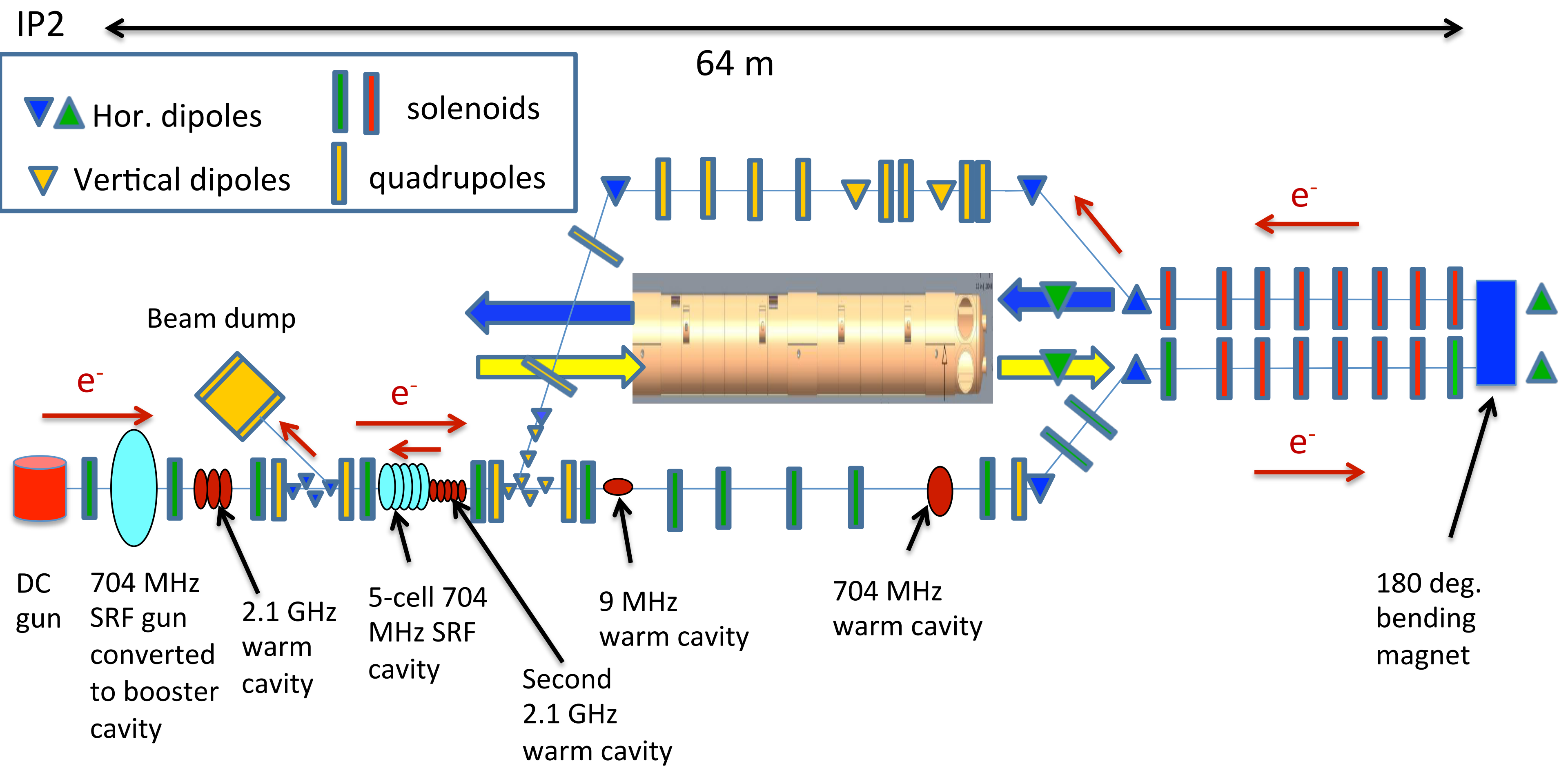
Igor Pinayev (BNL)

Low Energy RHIC electron Cooler LEReC

- First bunched beam electron cooler
- “Push-Pull” configuration
- Large energy range: 1.6 to 5 MeV
- Beam current up to 50 mA
- Bunch charge up to 300 pC
- Bunch trains 18 to 30 bunches
- Long beam transport with large space charge
- Normalized emittance $2.5 \cdot 10^{-6}$ m
- Energy spread $5 \cdot 10^{-4}$

LEReC Phase-II : ERL mode

electron beam energies 2.7 – 5 MeV



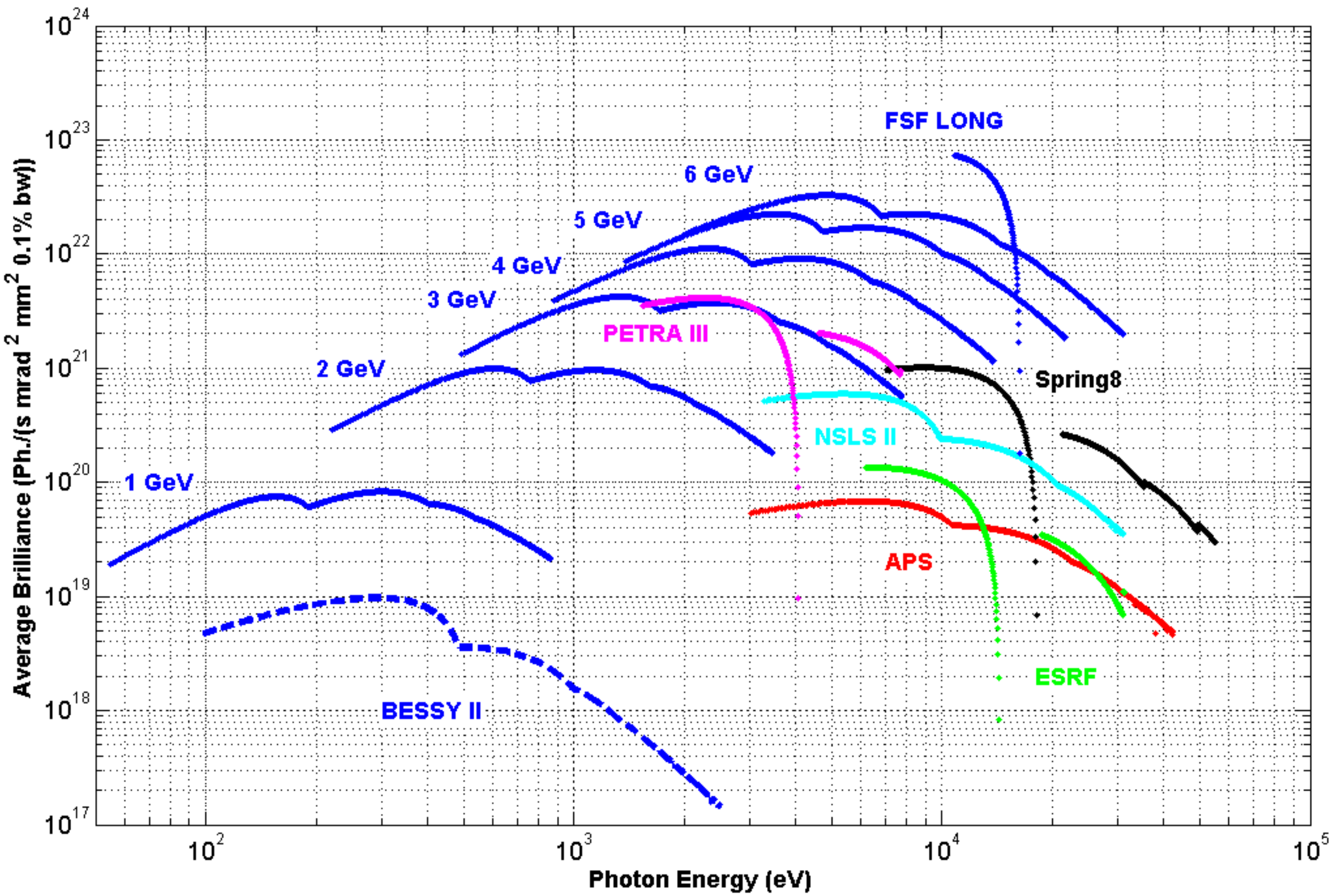
Jorg Kewisch (BNL)

ERL applications talks

- Light sources/ FELs
  - The Femto-Science Factory: A Multi-turn ERL-based Light Source, T. Atkinson
  - Design work of the ERL-FEL as the high intense EUV light source N. Nakamura
  - ERL as FEL driver, Y.Jing
  - Ultra-High Flux of X-ray/THz Source based on Asymmetric Dual Axis Energy Recovery Configuration, I. Konoplev

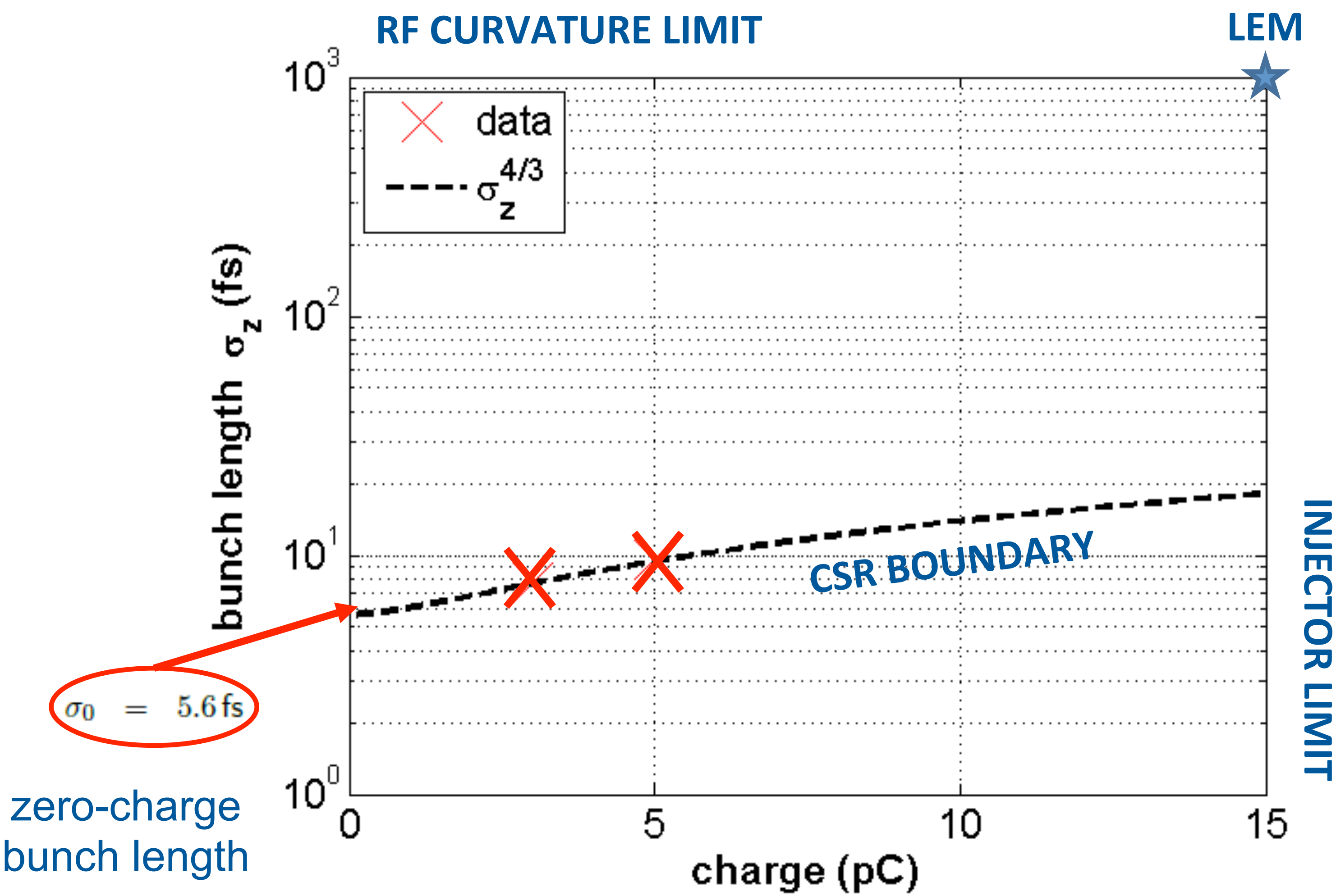
Femto-Science Factory Spectral Brightness

• High brilliance, full transverse coherence, high temporal resolution (ps → fs), multiple beam energies, CW operation … we need an ERL!



CSR Limitations of Short Pulse Mode

Terry Atkinson (HZB)



Energy loss due to CSR* $\Delta E_{\mathrm{CSR}} \sim q/\,(\sigma_t^2 - \sigma_0^2)^{2/3} \sim \mathrm{const}$

Summary(1/2)

N. Nakamura

- Design of a 10-kW class ERL-FEL EUV source (E=800MeV)
  - Injector (gun, SRF cryomodule, tracking)
  - Main linac (cavity, optics, HOM BBU and heating)
  - Arcs and chicane (lattice, optics)
  - Bunch compression simulation

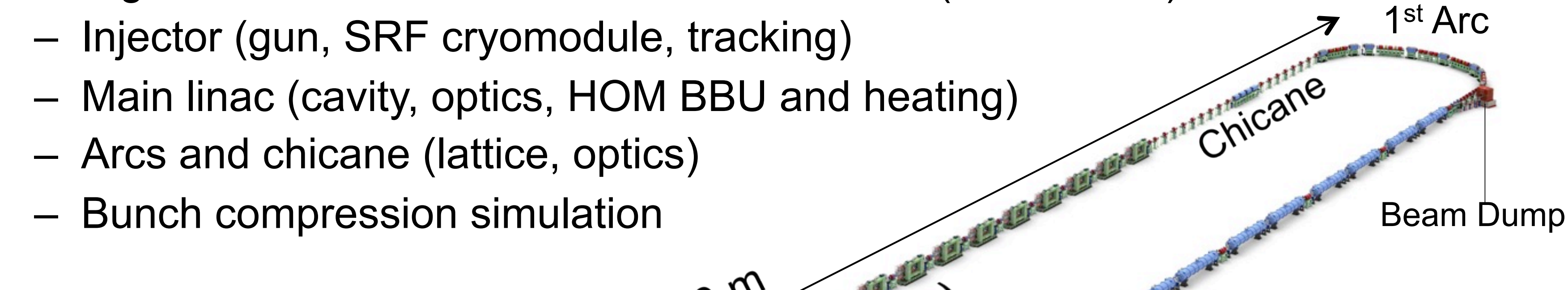
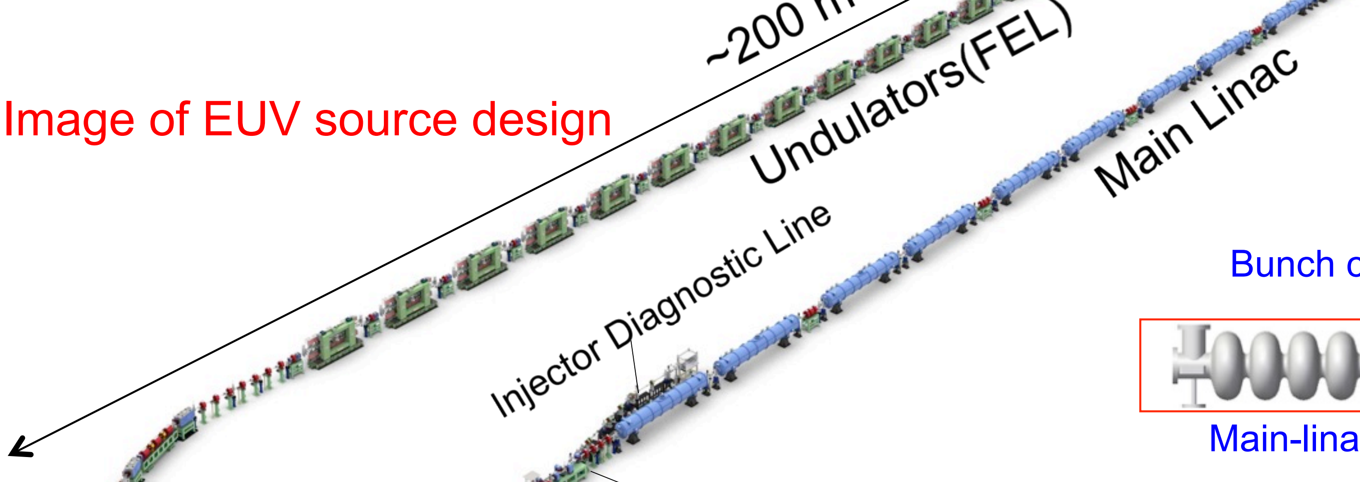
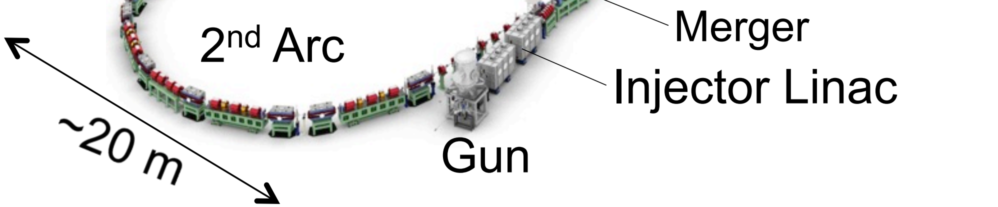
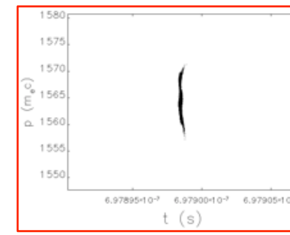
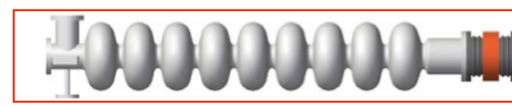




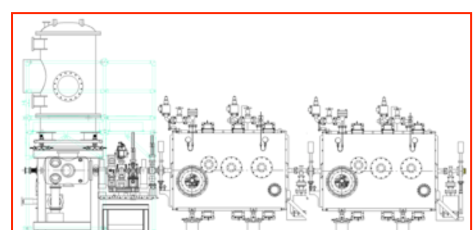
Image of EUV source design



Bunch compression(arc&chicane)



Main-linac cavity design

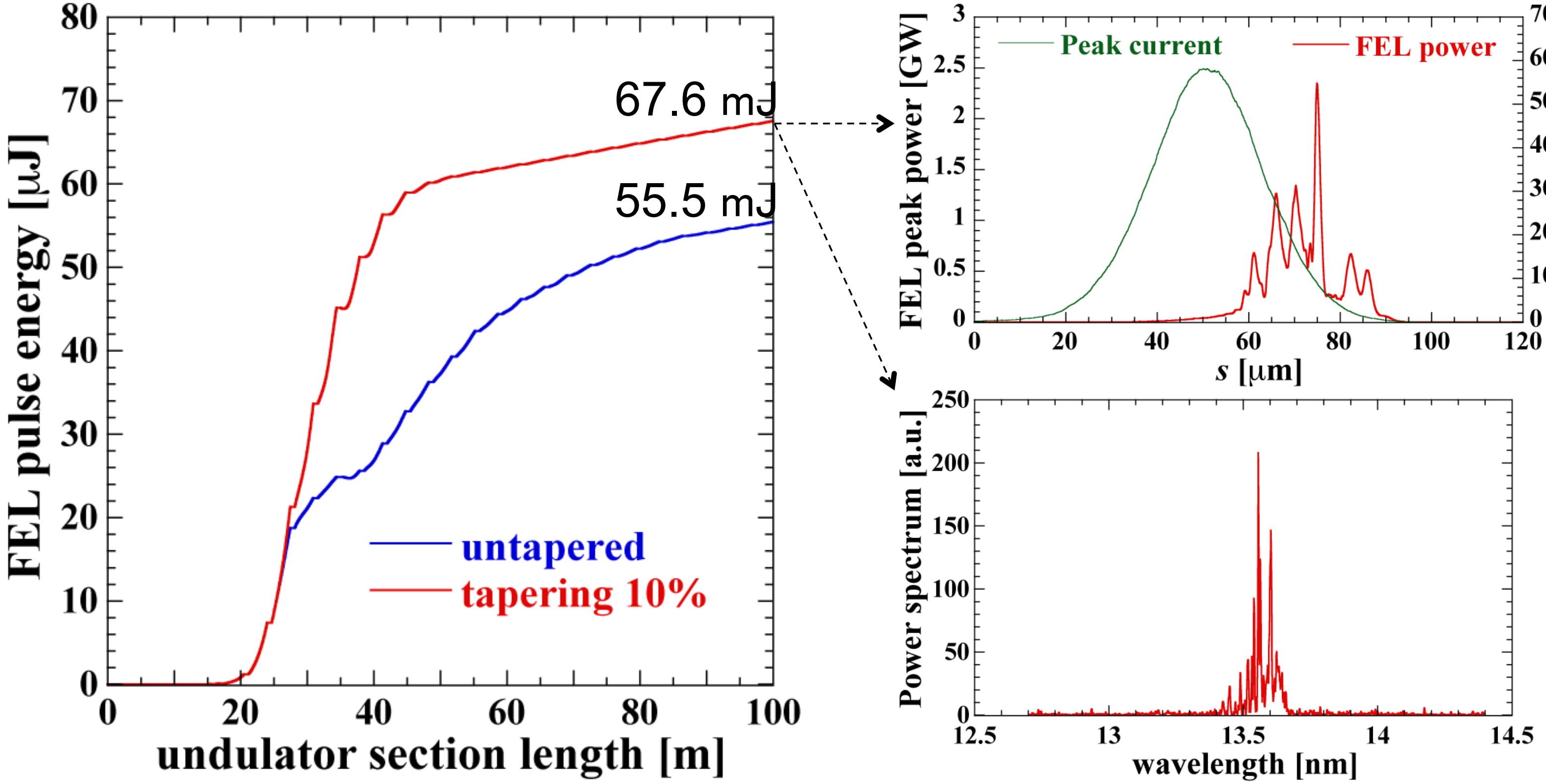


Injector design

Summary(2/2)

N. Nakamura

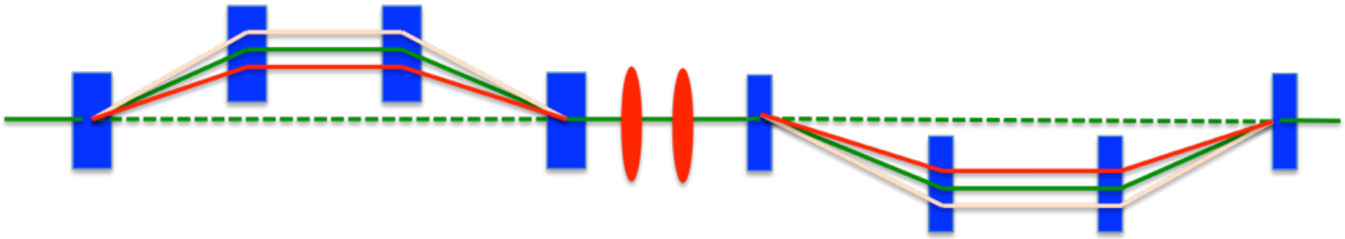
Electron beam parameters: E=800 MeV, Q_b=60 pC, f_b=162.5/325 MHz
Helical undulator parameters: K=1.652, l_u=28 mm, L_u=2.8m



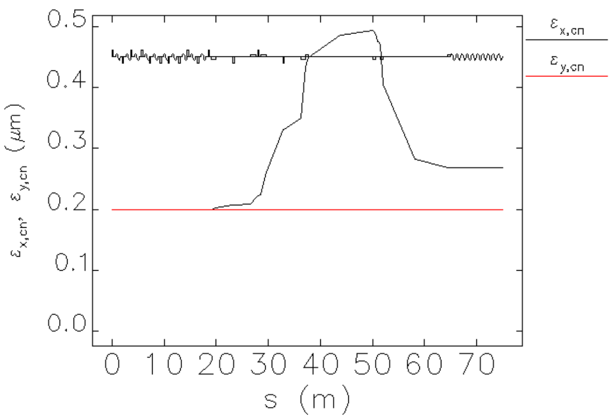
FEL power without tapering: 9.0/18.0 kW @ 9.75/19.5 mA
FEL power with 10% tapering: 11.0/22.0 kW @ 9.75/19.5 mA

Further design study and optimization is expected to improve the FEL performance.

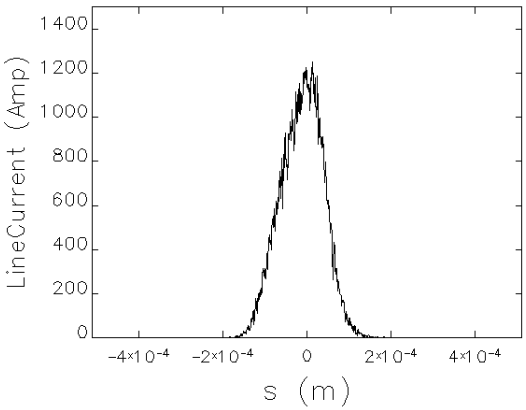
Zigzag chicane



PRSTAB. **16**, 060704(2013)



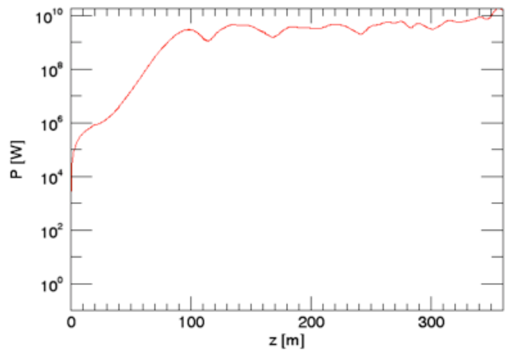
Normalized Emittance along Beamline

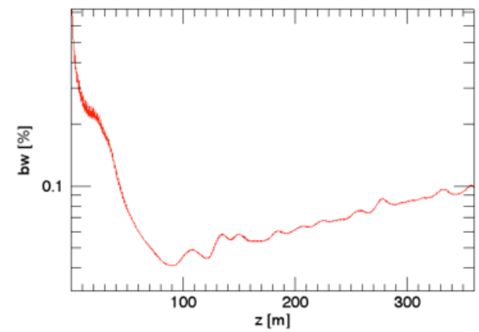


Beam current distribution after 2nd Bunch Compressor

Peak current (~ 1200 Amps) results in a 30 fold compression with CSR suppression scheme. A similar compression scheme has been applied to ATF2 upgrade to generate a 140+ fold compression with ~ 20% emittance growth.

MOPMN028, IPAC15





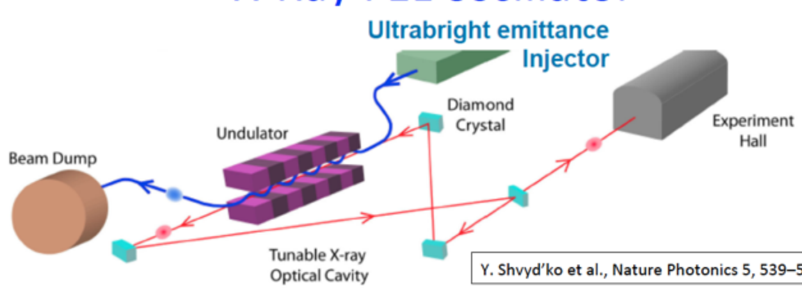
FEL reaches saturation in 100 m.

Parameter	LCLS	SCSS	XFEL	eRHIC,Hard X-FEL	eRHIC, Soft X-FEL
Energy (GeV)	14.35	8	17.5	10	1.8
Rep rate (Hz)	120	60	10	1×10^6	1×10^6
FEL wavelength (Å)	1.2	1	1	1	1×10^3
Peak brightness (ph/sec/mm^2/mrad^2/0.1%BW)	8.5×10^{32}	5×10^{33}	5×10^{33}	$\sim 10^{33}$	$\sim 10^{33}$
Average brightness (ph/sec/mm^2/mrad^2/0.1%BW)	2.4×10^{22}	1.5×10^{23}	1.6×10^{25}	$10^{26} - 10^{29}$	$10^{26} - 10^{29}$

Table 3: Comparison of eRHICs FEL with Projected Performance of X-ray FELs

Temporal coherence?

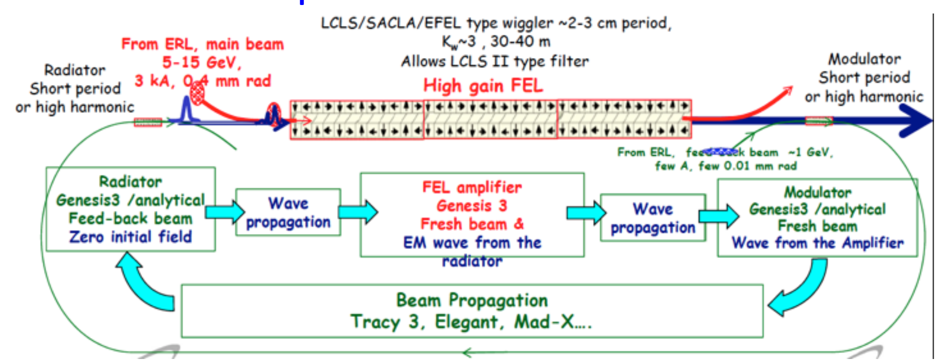
X-Ray FEL oscillator



Y. Shvyd'ko et al., Nature Photonics 5, 539–542 (2011)

©K.J. Kim

Optics Free FEL oscillator



©V.N. Litvinenko

UH-FLUX – conceptual layout

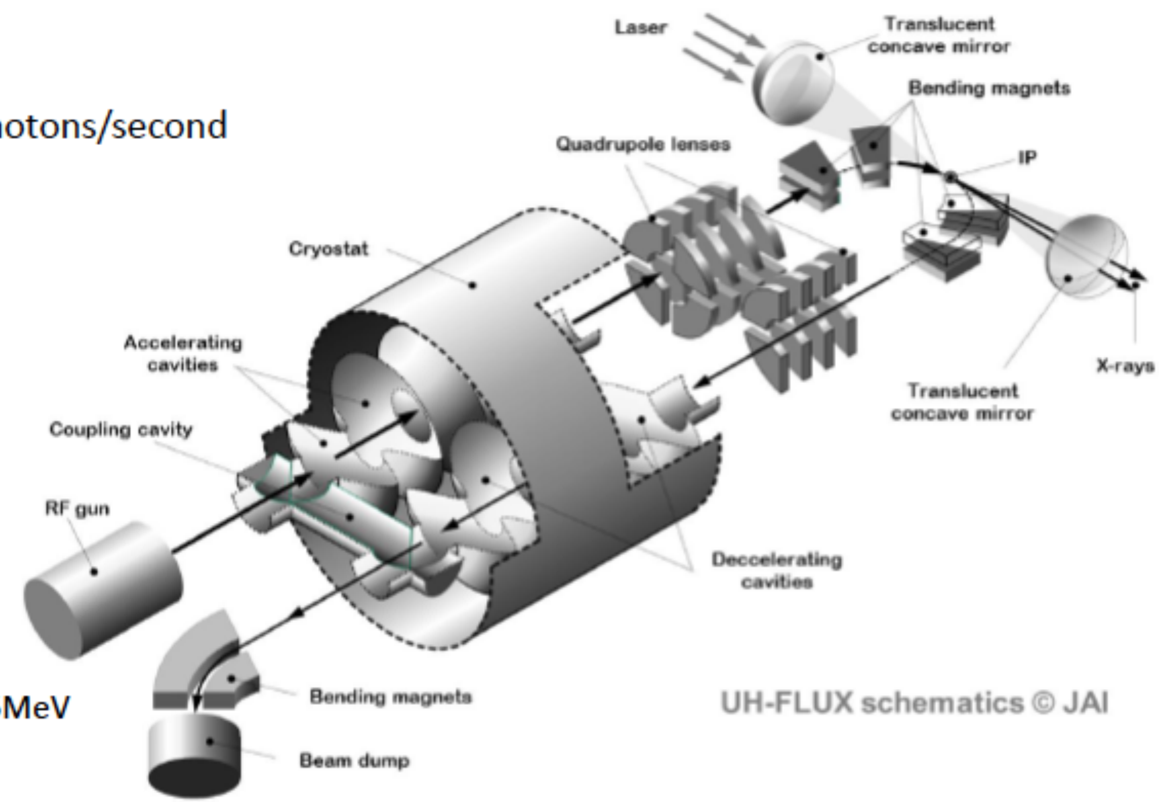
Generation of radiation: Compton Scattering (X-ray) or Coherent Smith-Purcell (THz)

1/ The peak brightness ~10^{23} -10^{24} photons /(mm^2 × mrad^2×s × 0.1%bandwidth)

2/ X-ray flux ~9×10^{12} - 3×10^{13} photons/second inside a 0.1% bandwidth

3/ THz output power up to 1MW

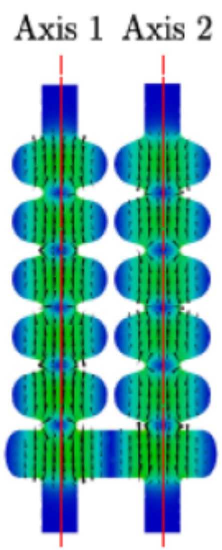
4/ Tunability from 0.1THz to 10 THz



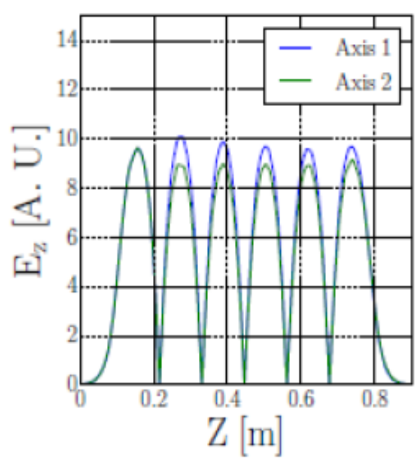
Electron beam energy range -10MeV to 35MeV
Electron beam current >1A
Operating frequency 1.3GHz
Configuration – two axis assymetric

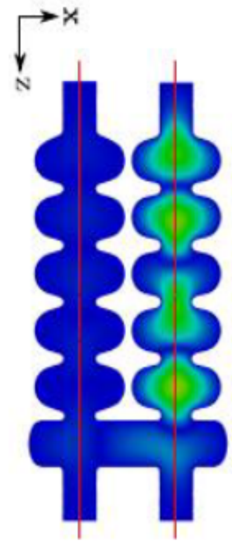
UH-FLUX: Asymmetric ERL

Electric field contour plot of operating eigenmode at 1.3GHz



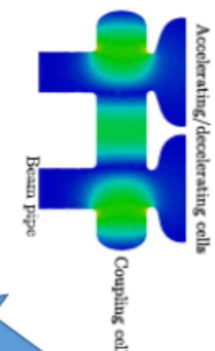
Operating field flatness @1.3GHz

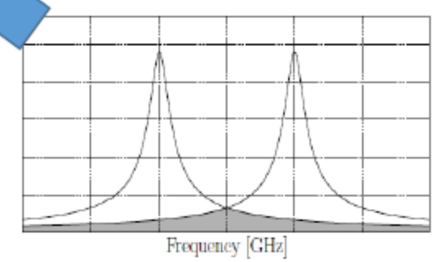




Electric field contour plot of dipole eigenmode at 1.73GHz

Electric field contour plot of resonant coupler eigenmode at 1.48GHz





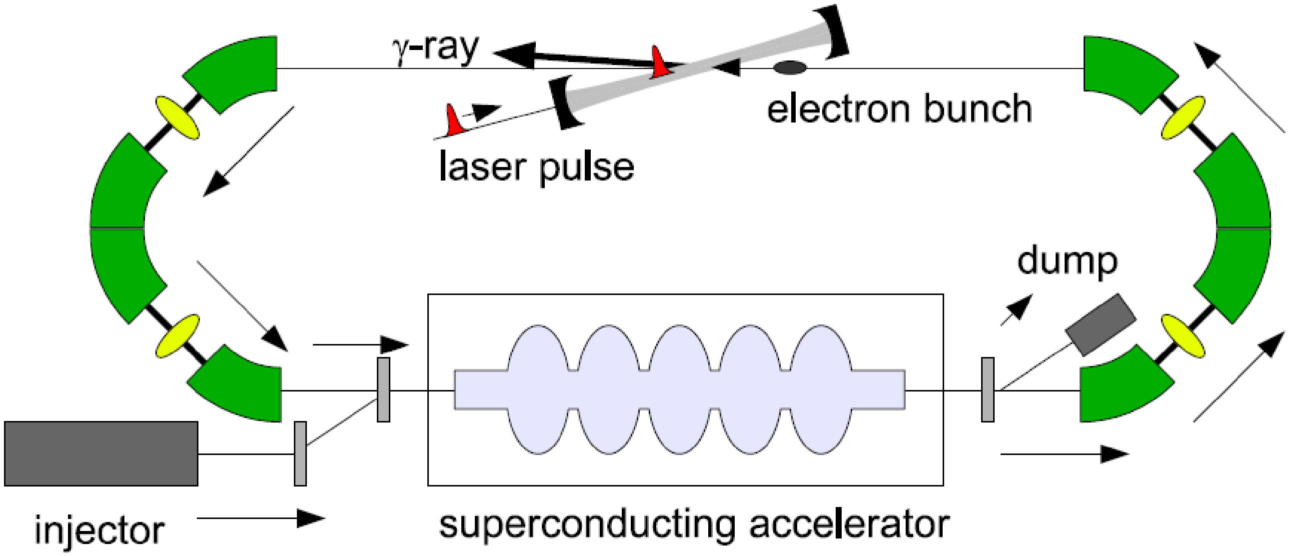
Schematic of HOMs separation (frequency domain) in acceleration and deceleration sections

Ivan Konoplev (JAI)

ERL applications talks

- γ-ray sources
  - Laser Compton Sources Based On Energy Recovery Linacs , R. Hajima
  - ERL as high intensity mono-energetic γ-ray sources, V. Yakimenko
  - An Inverse Compton Scattering Beamline for High-Energy, Time-Resolved X-ray Scattering Studies of Materials,

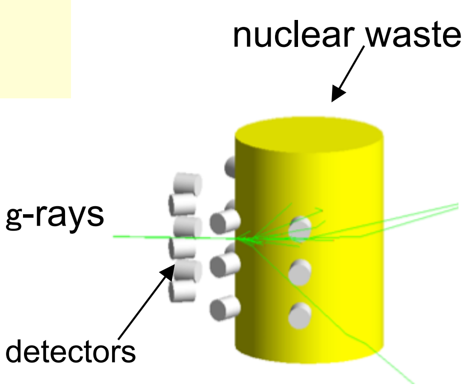
ERL-based Compton Source



- **Electron beam = 350 MeV, 13 mA**
- **Laser intracavity = 700 kW**
- **LCS ~2MeV, 1×10^{13} ph/s**

Next generation g-ray source

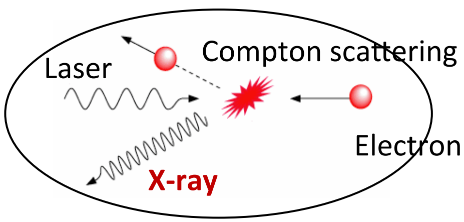
Management of nuclear material

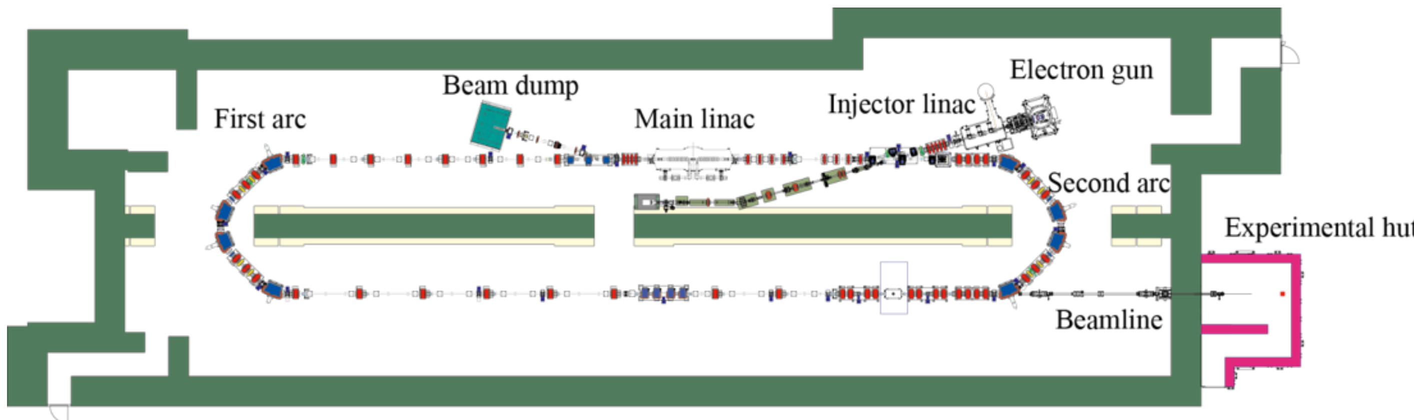


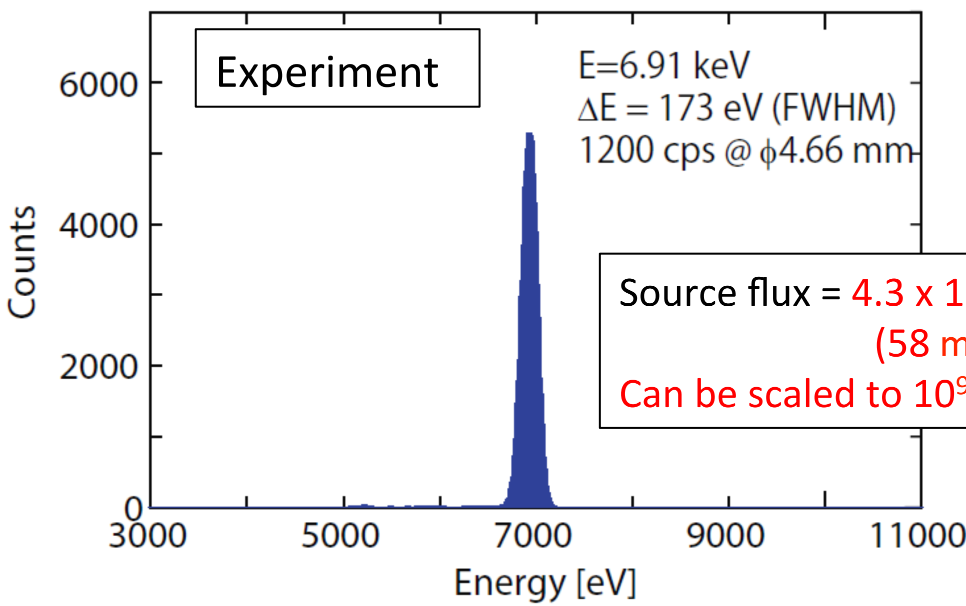
detection and assay of isotopes
-- U, Pu, and Minor Actinides
-- alpha emitter
-- difficult to measure by passive assay

Compton X-ray at cERL

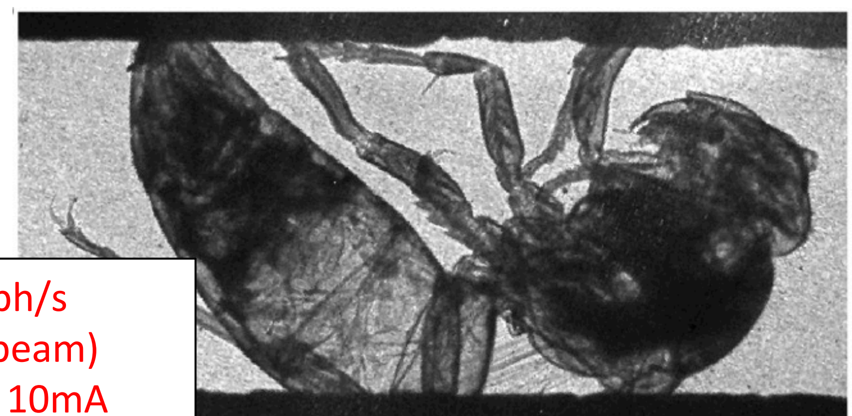
Demonstration of technologies relevant to future ERL-based Compton sources







Source flux = 4.3×10^7 ph/s
(58 mA beam)
Can be scaled to 10^9 at 10mA



An X-ray image of a hornet taken with HyPix-3000 from RIGAKU

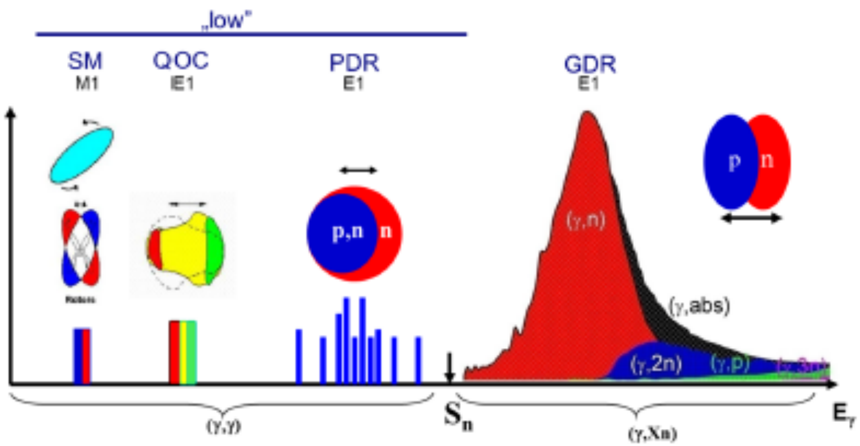
ERL as High Intensity Mono-Energetic Gamma-Ray Sources

V. Yakimenko,
June 10, 2015

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Motivation for a Compton based source



~100eV or 10nm, semiconductor industry, ~kW or 10^{20} photons/sec

~10keV, Compact synchrotron source, ~10^{9}-10^{12}/shot

~1MeV, Security applications ~10^{12}/s

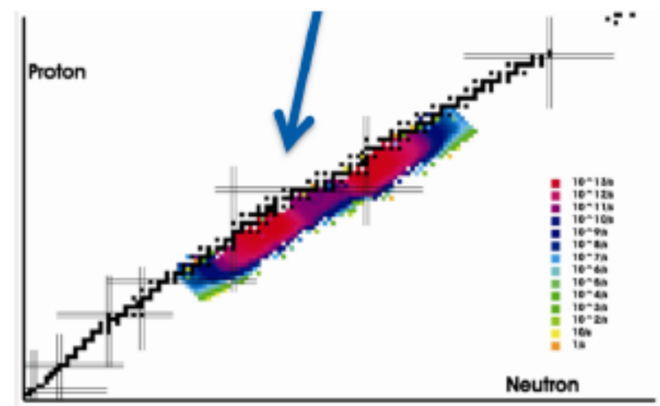
~15MeV,Isotope production, Nuclear physics ~10^{14-16}/s

~30-60 MeV Intense polarized positron source ~10^{16}/s

~150 MeV, Pion production ~10^{14}/s

Photofission of 238U was proposed by W. T. Diamond High energy (Chalk River) in 1999 as an alternative production method for RIB.

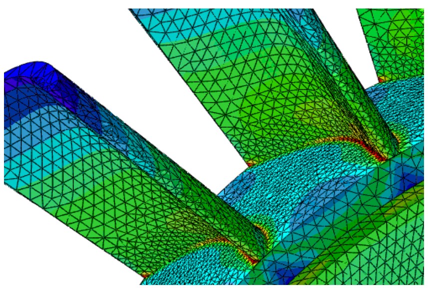
Smaller range & depth of products, with emphasis on neutron rich species.



An Inverse Compton Scattering (ICS) Source
for
High-Energy, Time-Resolved X-ray Scattering Studies
of
Structural Materials

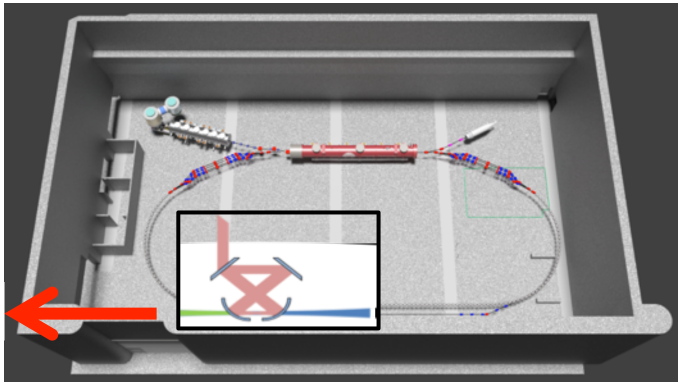
Joel D. Brock, Vaclav O. Kostroun, G. Hoffstaetter, **Bruce Dunham**
Cornell University, Ithaca, New York

A ‘small’ ERL using FFAG technology in combination with powerful laser can provide a unique hard x-ray beam in the 100 keV range for studying the microstructure of materials for many applications.



Component

X-ray output



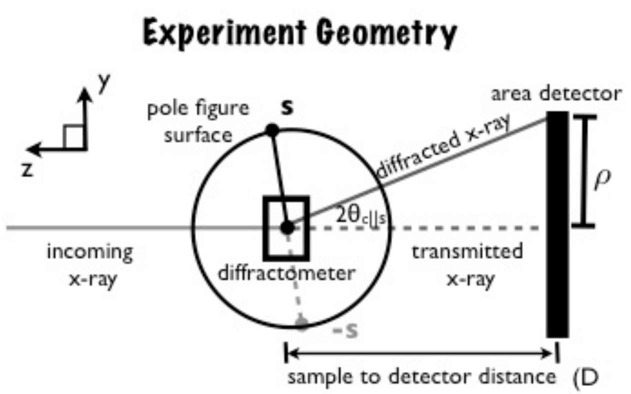
Experimental Challenge

Material Scientists and Structural Engineers want:

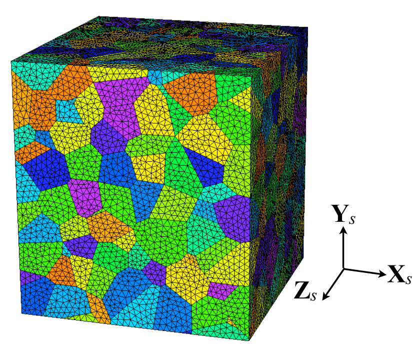
1. 50-200 keV x-rays for penetration through several mm of metal
2. Sub 1 µm spot (needs to be smaller than typical grain size)
3. High intensity > 10^{14} / second on sample (time resolution)

… resulting in an average brightness of

$$\mathcal{B} > 10^{20}\ \mathrm{ph/sec}/(\mathrm{mm}\cdot\mathrm{mrad})^2\cdot 0.1\%\mathrm{bw}\ \text{ at } \hbar\omega = 100\ \mathrm{keV}$$



A small ERL in combination with a high peak power laser + enhancement cavity comes close to meeting this requirement, allowing detailed studies of material grain structure and grain boundaries



Neper generated finite element mesh

Draft table of ERL parameters

Table ERL requirements for various applications

Application ERL parameter	eA/ep colliders	XUV/XRay FELs	γ-ray sources	SR sources	Nuclear Physics	THz/IR FELs	Electron cooling	Coherent Electron cooling
Energy, GeV	**20-60**	**0.65-10**	**0.1-10**	**3-7**	**0.2**	**0.01 – 0.2**	**1.6-5 MeV**	**0.1-0.2**
Number of passes	**3-16**	**1-4**	**x**	**1-2, 12**	**3**	**1-3**	**1**	**3**
Beam current, mA	**5-50**	**10-50**	**100**	**10- 100+**	**1**	**2-20 (within macropulse if pulsed)**	**50**	**100**
Peak current, A		**500 - 5000**	**1000**	**~ 100**	**?**	**20-200**	**0.35**	**10**
Charge per bunch, nC	**1-5**	**0.05 – 1**	**~ 1**	**0.01-1**	**pC**	**0.05-0.2**	**100**	**10**
Norm Emittance, mm mrad	**5-50**	**0.1 – 1**	**~ 1**	**0.1-1**		**2-20**	**2.5**	**<5**
Bunch length, mm	**4-10 mm**	**10– 100 µm**	**100 µm**	**3-100µm**		**0.1 – 0.5**	**15-35**	**200**
Energy spread	**10^{-3} 10^{-4}**	**$10^{-3} – 10^{-4}$**	**$10^{-3} – 10^{-4}$**	**10^{-4}**		**$10^{-2} – 10^{-3}$**	**$5 \cdot 10^{-4}$**	**$5 \cdot 10^{-4}$**
Electron Polarization	**>80%**	**N/A**	**?**	**(ligh**	**Yes**	**N/A**	**No**	**no**
Return arc energy acceptance		**1-5%**	**10%**	**10-3**		**Few percent**		
	VL	N	VL	TA, N, K		TA	JK	VL

Plan to update with the further inputs and distribute

Thanks to all presenters and participants

Q/A